

1 **BACKGROUND OF THE INVENTION**

2 1. Field of the Invention

3 An armature for an electromotive device and, more particularly, an induction coil  
4 having low resistance and high conductor density.

5 2. Prior Art

6 Wire wound armatures have long been known in the art pertaining to  
7 electromotive devices. More recently, armatures comprising electrical windings wherein  
8 the electrically interconnected conductor portions, which form the component coils, are  
9 printed onto the opposite sides of an insulating strip which is rolled up to form a spiral  
10 armature structure have been developed. In such an armature construction, the conductor  
11 portions (excluding the terminal ends thereof) are electrically connected to each other  
12 from one to the other side of the carrier strip by connecting means. The ends of the  
13 conductor portions are connected by way of a second printed winding section printed  
14 simultaneously with the first winding section configured parallel to the first winding  
15 section on the same insulating carrier strip (i.e., flex circuit board). This is for the specific  
16 purpose of forming complete, closed electrical current paths on the carrier strip before  
17 the carrier strip is rolled up to form the spiral armature structure. Accordingly, because  
18 the complete closed windings are formed on the flat strip prior to the rolling up of the  
19 strip, the windings are ready to use immediately upon rolling up of the strip. The  
20 disadvantage of such printed circuit type of armature construction is that the armature  
21 have a relatively high resistance due to the small conductor thickness and a relatively

1 large gap between conductors, the width of the gap being dependent on the thickness of  
2 the conductor traces and the limitations imposed on the gap width by the thickness of the  
3 conductive layer and the etching process itself. In addition, the presence of a backing or  
4 support material imposed by the structure reduces the packing density because the  
5 volume occupied by the support material reduces the volume available for conductive  
6 (copper) trace material.

7 Faulhaber, in U.S. Patent 3,944,857, discloses an air-core armature for  
8 electromotive devices comprising an elongated insulating strip (i.e., flexible circuit  
9 board) rolled up to form a spiral structure composed of a plurality of radially successive  
10 layers. In this construction, an armature winding is comprised of at least one armature  
11 coil. The armature coil is comprised of a plurality of electrically interconnected (e.g.,  
12 series connected or parallel-connected) component coils. Each of the component coils is  
13 formed of electrically interconnected conductor sections printed on both sides of the  
14 insulating strip. Each one of the component coils are located on different respective  
15 radially concentric layers of the spiral structure, but occupy substantially the same  
16 circumferential sector of the spiral structure, and accordingly are substantially juxtaposed  
17 in direction radially of the spiral structure. As discussed above, this construction provides  
18 an armature with relatively high resistance and interconductor gap width. Again, in  
19 addition to the relatively high resistance imposed by this construction, a substantial  
20 volume of the coil is occupied by the insulating strip thereby reducing packing density.

TOP SECRET

1 To overcome the aforesaid problems, including a relatively high resistance and  
2 low conductor density, inherent in armatures fabricated from flexible circuit boards,  
3 Graham et al., in U.S. Patent 6,111,329, the content of which is incorporated herein be  
4 reference thereto, disclose an armature fabricated from a pair of precision machined  
5 copper plates cut in a pattern to produce a series of axially extending conductors with  
6 each conductor being separated from (parallel) adjacent conductors by a slot. The  
7 precision machined plates are rolled to form two telescoping, hollow cylinders with each  
8 cylinder having a pattern of parallel conductors representing a half-electric circuit. The  
9 outer surface of the inner cylinder is wrapped with several layers of glass fibers for  
10 subsequent structural stability and mechanical separation. The glass fiber-wrapped inner  
11 cylinder is axially aligned inside the outer cylinder. The outer surface of the telescoped  
12 structure is also wrapped with several layers of glass fibers for subsequent structural  
13 stability. The conductive bands from the outer cylinder being the near mirror image of the  
14 conductive bands of the inner cylinder are helically coupled to form a complete electrical  
15 circuit. The resulting tubular structure is impregnated with an encapsulating resin for  
16 further structural stability and insulation. The result is a freestanding ironless core  
17 inductive armature coil. While the use of layered slotted metallic plated provides an  
18 armature having thicker conductors and a smaller gap therebetween (the metallic plate is  
19 etched from both sides), the etching process imposes limitations on the gap width that is  
20 related to the thickness of the sheet metal plate. Similarly, the construction of a die  
21 suitable for stamping the metal plates in order to provide narrow slots between parallel

1 conductors imposes practical limitations on the cost production of such an armature  
2 comprising the stamped plate due to the cost of sharpening and/or replacing the fragile  
3 die required to produce a narrow (1-10 mil) gap in a plate having a thickness greater than  
4 10 mil.

5 Due to the performance and/or cost limitations inherent in prior art induction  
6 coils, particularly induction coils comprising armatures, there remains a need for an  
7 induction coil having high conductor density, low electrical resistance and a method for  
8 making the induction coil.

#### 9 SUMMARY

10 The present invention discloses an induction coil suitable for use as an armature in  
11 an electromotive device. The induction coil comprises a plurality of tubular members  
12 wherein an outer tubular member coaxially overlies an inner tubular member. Each  
13 tubular member comprises a plurality of elongate, parallel, electrically conductive strips  
14 having a gap between adjacent electrically conductive strips. Each of the parallel  
15 conductive strips comprising a tubular member most preferably has a rectangular cross  
16 section, a strip width and a strip thickness. The gap between adjacent conductive strips in  
17 a tubular member is less than 50% of the strip thickness and preferably about 10% of the  
18 strip thickness. Each of the tubular members is made by the superimposing first and  
19 second metallic plates, each plate having a plurality of slots separating adjacent  
20 conductive strips. The slots between adjacent conductive strips have a slot width that is  
21 greater than the strip width and the gap width. The first and second plates are

1 superimposed in such a way that the conductive strips on the first plate overlie  
2 corresponding slots in the second plate. Pressure is then applied to the first and second  
3 plates to force the conductive strips in the respective plates into the corresponding slots in  
4 the other plate so that the conductive strips on both plates are coplanar and form a  
5 composite sheet wherein a portion of the composite sheet is laminate and another portion  
6 of the composite sheet bearing the conductive strips is coplanar. The composite sheet is  
7 then rolled into a cylinder. The induction coil is then assembled from two or more  
8 tubular members in accordance with the method disclosed in U.S. Patent 6,111,329,  
9 discussed above. The gap between conductive strips in the induction coil is less than 50%  
10 of the strip thickness.

11 The features of the invention believed to be novel are set forth with particularity  
12 in the appended claims. However the invention itself, both as to organization and method  
13 of operation, together with further objects and advantages thereof may be best be  
14 understood by reference to the following description taken in conjunction with the  
15 accompanying drawings in which:

#### 16 17 **BRIEF DESCRIPTION OF THE DRAWINGS**

18 Figure 1 is a top view of a first slotted metallic sheet used to form a tubular  
19 member, which, in turn, is used to fabricate an induction coil in accordance with a  
20 preferred embodiment of the present invention.

1 Figure 2 is a top perspective view of a first slotted metallic sheet being positioned  
2 to overlie a second slotted metallic sheet.

3 Figure 3 is a top view of the two slotted metallic sheets in accordance with  
4 Figures 1 and 2 after superposition and compression of the sheets to form a laminate  
5 structure.

6 Figure 4 is a perspective view of the laminate structure illustrated in Figure 3,  
7 rolled from bottom to top to form a cylinder.

8 Figure 5 is a cross-sectional view of the cylindrical member of Figure 4, taken  
9 along section line 5-5.

10 Figure 6 is an enlarged portion of the cross-sectional view of the cylindrical  
11 member of Figure 5 showing the structure of the edge of the cylindrical member.

12 Figure 7 is a top view of a slotted sheet of conductive material, the slots being  
13 adapted to registerably receive a conductive strip, such as the member indicated at  
14 numeral 80 (Figure 8) therewithin.

15 Figure 8 is a top view of a strip of conductive material dimensioned to fit within a  
16 slot of the sheet 70 of Figure 7 to provide a small gap between adjacent conductive strips.

17 Figure 9 is a top view showing two sheets of pre-cut or pre-formed conductive  
18 material for making a slotted sheet of conductive material in accordance with a third  
19 embodiment of the present invention.

20 Figure 10 illustrates a slotted sheet wherein the two sheets of pre-formed  
21 conductive material of Figure 9 wherein the conductive strips on respective sheets are

1 interleaved (i.e., matingly fitted together so that the conductive strips on the sheets are  
2 juxtaposed) to form a slotted sheet in accordance with a third embodiment of the present  
3 invention wherein the width of the gaps between adjacent conductive strips in the  
4 interleaved sheet are uniform in size and less than the thickness of the conductive strips.

### 5 DESCRIPTION OF THE PREFERRED EMBODIMENTS

6 The introduction of induction coils comprising a plurality of slotted metal sheets  
7 or plates in accordance with the prior art provides a free-standing coil having lower  
8 resistance than wire wound or printed circuit-type coils. To further improve the electrical  
9 characteristics of metal plate coils, it is desirable to minimize the gap width between  
10 conductive strips and increase the thickness of the conductive strips. Prior art machining  
11 methods have inherent practical limitations, which impose a strip thickness/gap size ratio  
12 that is substantially constant. In a first preferred embodiment of the present invention, a  
13 tubular member adapted to be mated with a similar member to form an induction coil  
14 having relatively thick conductive strips, when compared to conventional coils, and a gap  
15 width that is substantially independent of strip thickness is disclosed.

16 With reference to Figure 1, a slotted metallic plate 10 having a plurality of slots  
17 11 interposed between parallel conductive strips 12 is shown in top view. The plurality of  
18 slots 11 have a slot width  $W$  that is slightly greater than the conductive strip width  $w$ .  
19 Owing to the relatively large slot width  $W$ , the slots 11 can be inexpensively cut in the  
20 metallic plate 10 by any precision machining method such as chemical etching or  
21 stamping. When two slotted metal plates 10 are superimposed such that the conductive

1 strips 12 on the metallic plate 10 overlie the slots 11' in a second metallic plate 10', as  
2 shown in Figure 2 and formed, such as, for example, by compression, to force the  
3 conductive strips 12 on the first slotted metallic plate 10 into the corresponding slots 11'  
4 on the second slotted plate 10', a composite sheet 30 is formed as illustrated in top view  
5 in Figure 3.

6 Figure 3 is a top view of the two slotted metallic sheets 10 and 10' in accordance  
7 with Figures 1 and 2 after superposition and compression of the sheets to form a  
8 composite sheet 30. In the composite sheet 30, the conductive strips 12 on slotted plate 10  
9 substantially fill the slots 11' of slotted sheet 10', leaving a small gap 31 between  
10 adjacent conductive strips 12 and 12' in the composite sheet 30. The thickness of the  
11 conductive strips 12 and 12' will depend, of course, on the thickness of the metal plates  
12 used to make the slotted metallic plates 10 and 10'. For example, if the thickness of the  
13 sheets used to make slotted metallic plates 10 and 10' is 20 mil, the gap width 31 may be  
14 as small as 1-2 mil in the composite sheet, the gap width being limited only by the  
15 requirement that the gap width be sufficiently large to provide electrical isolation between  
16 conductive strips without arcing or voltage breakdown in the gap. The composite sheet 30  
17 is then rolled to form a cylindrical member.

18 Figure 4 is a perspective view of the composite sheet 30, illustrated in Figure 3,  
19 rolled to form a cylindrical member 40. Figure 5 is a cross-sectional view of the  
20 cylindrical member 40 taken along section line 5-5 of Figure 4. An enlarged portion of  
21 the edge of the cylindrical member, viewed along section line 5-5, is shown in Figure 6.



1 After opposing edges of the slotted sheet 30 are brought together, they are affixed to one  
2 another to form a tubular member 50 for use in the assembly of an induction coil in  
3 accordance with a first preferred embodiment of the present invention and the assembly  
4 method disclosed in U.S. Patent 6,111,329.

5 Turning now to Figures 7 and 8, an induction coil in accordance with a second  
6 preferred embodiment of the present invention is described. A slotted metallic plate 70 is  
7 made by stamping, etching or machining a plurality of identical, parallel slots 71 into a  
8 metallic sheet. The lateral ends 72 of the slots 71 are shaped to receive the lateral ends 82  
9 of a modular conductive strip 80 in registrable relationship therewith. The width of the  
10 modular conductive strip 80 is less than the width of the slots 71 in the slotted metallic  
11 plate 70 in order to leave a small gap between adjacent conductive strips 73 and 80 when  
12 the conductive strips 80 are disposed within the slots 71. When a plurality of the strips 80  
13 have been disposed to fill all the corresponding slots 71, the lateral ends 82 are fused or  
14 otherwise mechanically or materially connected to the metallic plate 70 and the resulting  
15 slotted metallic sheet rolled and assembled to form an induction coil as discussed above.

16 A third preferred embodiment of a slotted conductive sheet useful for making an  
17 induction coil and a method for making the slotted sheet is illustrated in Figures 9 and 10.  
18 Turning first to Figure 9, two formed sheets 90 and 91 are formed or stamped to provide a  
19 plurality of conductive strips 92 and 92' respectively. The conductive strips 92 and 92'  
20 are attached to a support strip 93 and 93' at a lateral edge thereof. The opposing free end  
21 95 and 95' of the conductive strips 92 and 92' have registration means 96 and 96' thereon

1 that matingly and registerably engage mating registration means 97' and 97 on the  
2 support strips 93 and 93'. The slotted sheets 90 and 91 are matingly juxtaposed with each  
3 other in registrable alignment, as shown in Figure 10, and the free ends 95 and 95' of the  
4 conductive strips are affixed to the engaging means 97' and 97 respectively on the  
5 support strips 91 and 90 respectively to form a slotted sheet 100. The gap 98 between  
6 conductive strips 92 and 92' in slotted sheet 100 is preferably less than the thickness of  
7 the conductive strips 92 and 92' (the thickness of the conductive strips 92 and 92' is not  
8 visible in Figures 9 and 10).

9 It has been shown that induction coils having a packing density greater than  
10 heretofor deemed possible in the art can be achieved by the novel slotted sheets of  
11 conductive material described hereinabove. Embodiments of the slotted sheets can be  
12 made by three different methods as described. While particular embodiments of the  
13 present invention have been illustrated and described, it would be obvious to those skilled  
14 in the art that various other changes and modifications can be made without departing  
15 from the spirit and scope of the invention. It is therefore intended to cover in the  
16 appended claims all such changes and modifications that are within the scope of this  
17 invention.

18 What we claim is:  
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